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SLEEP LOSS EFFECTS ON CONTINUOUS SUSTAINED PERFORMANCE:

Behavioral Analogs of the REM-nonREM Cycle

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About-90-minute cycles in various waking behaviors have been described, including a 90-minute alternation in hemispheric dominance. To confirm this finding, 11 healthy young subjects were isolated for 10 hours. Letter-matching and spatial dot-matching tasks were administered every 10 minutes, while sleepiness, fantasy, eating, and drinking were also monitored. No about-90-minute cycle in letter-matching, dot-matching, or their ratio was found, but weak evidence appeared for cycles in eating, drinking, and restroom trips.

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Since Kleitman first presented his hypothesis that there is a "Basic Rest-Activity Cycle," (BRAC), (1), several groups have searched for behavioral expressions of this cycle in waking life. Quite a variety of behavioral cycles with periods of about 90 minutes have been described. For example, Friedman and Fisher (2) described a rhythm in oral behaviors. Globus et al. reported about-90-minute rhythms in the Rorschach responses and in activity (3,4). Lavie reported rhythms in the spiral after-effect illusion and in certain performance tasks (5,6). Kripke (7) found 10-20 cycle/day frequencies in EEG measures and in lever-presses for water among isolated subjects. Kripke and Sonnenschein (8) described such a rhythm in subjective fantasies.

These positive reports must be taken with a grain of salt, because most of these studies (including our own) had rather few subjects, some weaknesses in statistical techniques, and partially equivocal results. In addition, there has been difficulty in replicating some of the results. For example, in further replications in our laboratory, we have not consistently found a 90-minute rhythm in fantasies -- the spectral peak is closer to one cycle per 180 minutes when results from about 50 separate subjects are averaged. Some negative findings should also be noted. For example, we found that there is no 90-minute rhythm in gross activity itself (9). Thus, if there are 90-minute cycles in some behaviors, gross activity is a poor representative and "basic rest-activity cycle" is a misnomer. Also, it has been shown that the about-90-minute cycle in stomach contractions, first reported by Wada (10), is not related either to Stage REM sleep or to daytime fantasies (11,12). Thus, we must consider that there are multiple pacemakers with about the same frequency, and we become obliged to sort out which is which (13).

One of the most intriguing descriptions of 90-minute cycles has been the report of Klein and Armitage (14), who described a "1½-hour oscillation in cognitive style." Two simultaneous matching tasks were tested, which were thought to reflect asymmetrical hemispheric specialization. A verbal task required deciding whether pairs consisting of one uppercase and one lowercase letter represented the same letter of the alphabet. A spatial perception task required a decision as to whether pairs of seven-dot random patterns were identical. Responses were recorded with paper and pencil. Each task was performed for 3 minutes every 15 minutes for 8 hours. Eight young subjects were tested together in a room on a single day and the experimenters were apparently present during the tasks. Spectral peaks were described at frequencies of approximately 1 cycle per 96 minutes in both tasks, however, the 96-minute peak was neither the only significant spectral peak nor the most prominent. Performance varied inversely between the tasks. Results were interpreted as suggesting a BRAC-like cycle in hemispheric dominance.

Excited by this report, we decided to repeat the study with certain elaborate precautions including isolation of subjects, computerized testing, and control of motivation.

METHODS

Eleven young volunteers, 3 females and 8 males (ages 18-32) served as subjects. All were students recruited by advertisements. All were right-handed and from right-handed families.

A microcomputer system was employed to present performance tasks, regulate the timing of the performance trials, score performance and reward subjects, and record the results. There were three different tasks and 5 subjective measures during each 10-minute interval. First, for 3 minutes, a

letter-matching task with uppercase and lowercase letters was displayed on the computer screen. Subjects worked as rapidly as possible, responding by typing "S" on the keyboard if the letters were the same and "D" if they were different. A harsh sound provided negative feedback for errors. Next, for 3 minutes, pairs of random 7-dot patterns were displayed, some identical and some different, and "S" and "D" responses were again required and feedback given. Next, for 3 minutes, a brief automated version of the Wilkinson Auditory Vigilance Task was presented (15). In the last minute, subjects were asked to give visual-analog self-ratings on sleepiness and attention-fantasy scales and to indicate how much they had had to eat, how much they had had to drink, and whether they had visited the restroom during the prior 10-minute interval. Since it was possible to respond to these latter queries within about 15 seconds, approximately 45 seconds was provided for rest, snacking, and restroom trips before resumption of the task presentations. Food in snack-sized quantities and non-caffeinated beverages were provided ad lib, but the task presentation was not halted for eating, drinking, or restroom needs. Drinks were quantified in 30 cc cups and snack foods were assigned arbitrary units.

Subjects were paid $2.00 per hour for participation in the experiment plus up to an additional $2.00 per hour based on the excellence of their performance. After each 3-minute task, and again at the end of each 10 minutes, the computer informed the subject how much s/he had earned as well as the hourly earning rate achieved. Thus, the computer supplied continuous feedback to maintain the subjects' interest and motivation.

Subjects made an initial visit to the laboratory to learn about the experiment, sign voluntary informed consent, and practice the tasks to familiarize themselves with the experimental setting. A few days later, they

returned to the laboratory and worked continuously at the performance tasks for a 10-hour period from approximately 8:00 A.M. to 6:00 P.M. Each subject worked alone in a lighted 3 x 3.5 m. room. Other than brief visits by experimenters to replenish the food and monitor any equipment difficulties, each subject was undisturbed. Subjects were permitted to briefly leave the laboratory to visit the restroom.

Six scores for each performance were obtained each hour, or 60 over the course of each 10-hour experiment. To examine for rhythmic processes, the means from each time series were removed and the autocorrelation functions and hanned spectral transforms computed with a spectral resolution of 0, 4.6, 9.2, 14.4, 18.0....64.4 cycles/day (16). A spectral peak at one cycle per 100 minutes or 14.4 cycles/day was prospectively predicted. For the group of subjects, the mean and confidence limits of the individual spectra were computed for each variable. Product-moment correlations among variables were also computed.

RESULTS

Most subjects performed steadily and relatively consistently throughout the study. It was necessary to excuse one male subject when it was discovered that he was taking frequent breaks from the tasks and not complying with the protocol. Thus data for 10 subjects were analyzed. Subjects performed the Wilkinson Auditory Vigilance Task without error in the majority of 3-minute test intervals, so these data could not be analyzed for changes over time.

The letter-matching and dot-matching tasks were substantially correlated. Taking the z-transform of r (the product-moment correlation coefficient) to obtain the mean for the group, an average positive correlation of $r=0.59$ was found ($t=5.90$, $p<0.002$ for the mean correlation). Neither the sleepiness

nor fantasy ratings were significantly correlated with either dot-matching or letter-matching. Restroom trips had a small negative correlation with letter-matching, only ($r=-0.25$, $t=2.24$, $p<0.05$), but obviously could not account for much covariance. Eating and drinking were not significantly correlated with either task performance.

Plots of the performance and subjective responses of each subject showed no impressive cyclicity in the range of 80-120 minutes in any measure. The spectra for letter-matching and dot-matching peaked in the 4.8 cycles/day band (1 cycle per 300 min) and dropped off rapidly at higher frequencies (Figures 1 and 2). The spectrum for the ratio of letter-matching to dot-matching performance, representing the relative performance in the two tasks, also peaked at 4.8 cycles/day, but the spectral variance was as great in the slowest frequency band (0-2.9 cycles/day). The spectra for sleepiness and the attention-fantasy scale also peaked in the 0-2.9 cycles/day band. For both eating and restroom trips, the spectra were rather flat, and there was no frequency significantly exceeding the expectation for random variance, however, the greatest spectral amplitudes were in the 14.4 cycles/day frequency band (1 cycles per 84-124 min). The spectrum for eating is shown in Figure 3. A substantial peak in drinking behaviors was noted in the 9.6 cycles/day band, significantly exceeding random variance but not significantly exceeding the variance in the adjacent 14.4 cycles/day band.

DISCUSSION

These results fail to confirm the results of Klein and Armitage (14). They lend no support whatsoever to the hypothesis that there is an about-90-minute cycle in performances modulated by alternating hemispheric dominance.

Quite a few possibilities might have caused the inconsistency between our results and those of Klein and Armitage (14). Our computer presentation

of the tasks must have somewhat altered the speed of responding to the letter- and dot-matching tasks. Our demand characteristics were quite different, since we supplied immediate feedback and monetary rewards. Our model placed much more pressure on the subjects, allowing almost no rest, and each subject was socially isolated. Also, our spectral method was quite conservative. In contrast, since all of Klein and Armitage's subjects worked in the same room, it is conceivable that group interactions (e.g., at lunch) or interactions with the experimenters might have biased the results and degraded the independence of subjects. Since Klein and Armitage found that three of 15 tested spectral frequencies were significant, the 96-minute frequency was not the most prominent, and the other frequencies found were not predicted a priori, there is some doubt whether their statistical approach yields a conservative estimate of rhythm detection. A most striking disparity was in the relative performance on the dot-matching and letter-matching tasks, where Klein and Armitage found inversely varying performances and we found positively correlated performances. It would thus appear that these measures are quite situationally sensitive, which raises doubt as to their generalizability as measures of hemispheric dominance.

It is interesting that we found some weak evidence for cycles at frequancies of 9.6-14.4 cycles/day in eating and drinking behaviors. Cycles in eating and drinking have been reported in several human isolation experiments (2,7,17), and rather similar cycles have been described in primates both in isolation and in social-living models (18,19,20,21). Perhaps the similarity of frequency of the primate cycles is surprising, since the REM-nonREM cycle frequencies of monkeys are about twice those of human adults. Enteric contraction cycles are more similar in frequency among species than are their REM-nonREM cycles (22), which provides another indication that enteric con-

traction cycles and REM cycles originate from different pacemakers. Since feeding cycles, like enteric contraction cycles, seem rather stable in frequency across species, feeding cycles are more likely to be related to enteric contraction cycles than to REM-nonREM cycles.

The possible rhythm noted in restroom trips was not convincing, both because the spectral peak was insignificant and because this measure was highly discontinuous. Nevertheless, it is interesting to note that urinary excretion volumes have been reported to show similar cycles (23). Urinary excretion cycles are also not strictly associated with the REM-nonREM cycle (24).

In summary, this experiment was rather negative as regards the hypothesized waking rhythm in hemispheric dominance. Only very weak support was found for previously described rhythms in eating and drinking. Over the years, impressive difficulties have arisen in finding replicable behavioral expressions of the hypothesized BRAC. There seems to be sufficient evidence that some sorts of cyclicity are found in waking humans, on the other hand, these cycles are neither so regular nor so replicable as the BRAC theory might suggest. The cyclic behaviors which have been described seem quite sensitive to situational factors and small variations in experimental designs. At the present time, extreme caution is needed in generalizing about 90-100 minute cycles in human behavior.

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FIGURE 1:

The mean of 10 spectra for 10 subjects, surrounded by its 95% confidence limit, is shown for the number of dot-pairs matched correctly. The ordinate is the percent of the total variance in each frequency band.

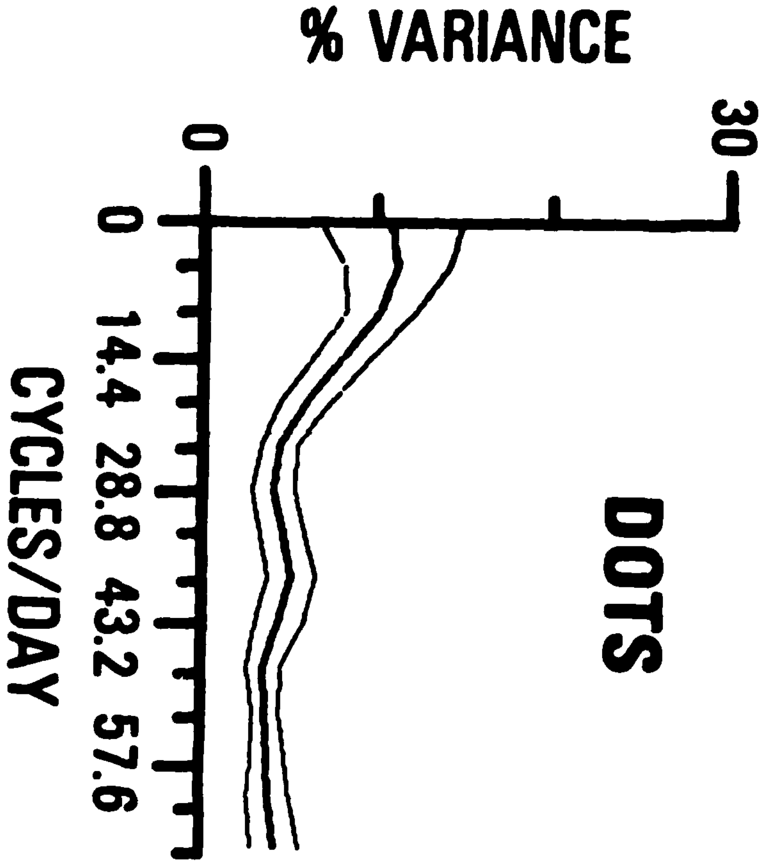


FIGURE 2:

The mean spectrum for letter-pairs matched correctly.

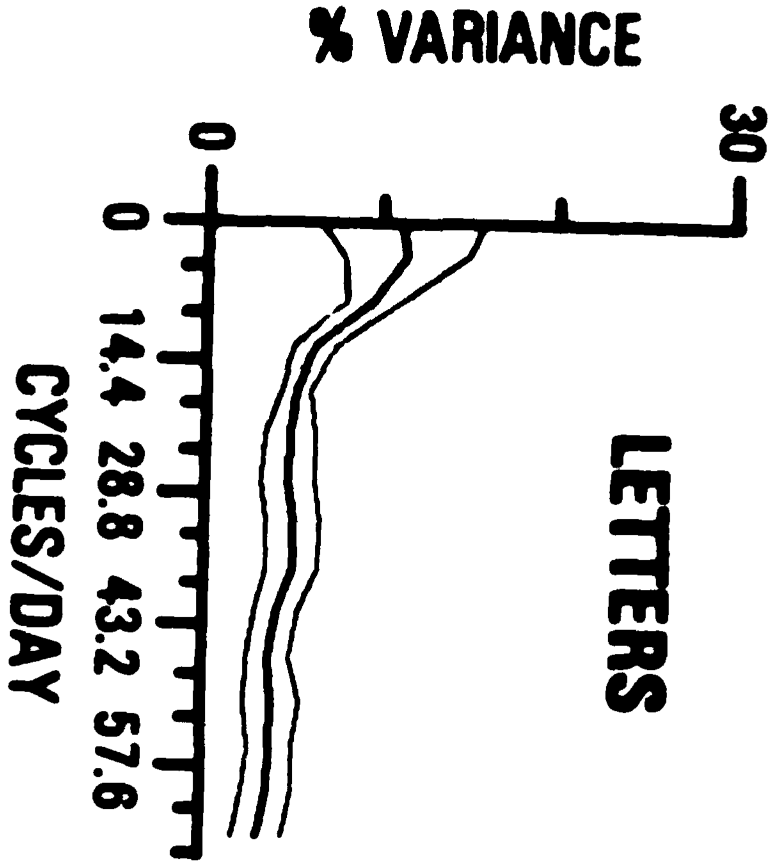
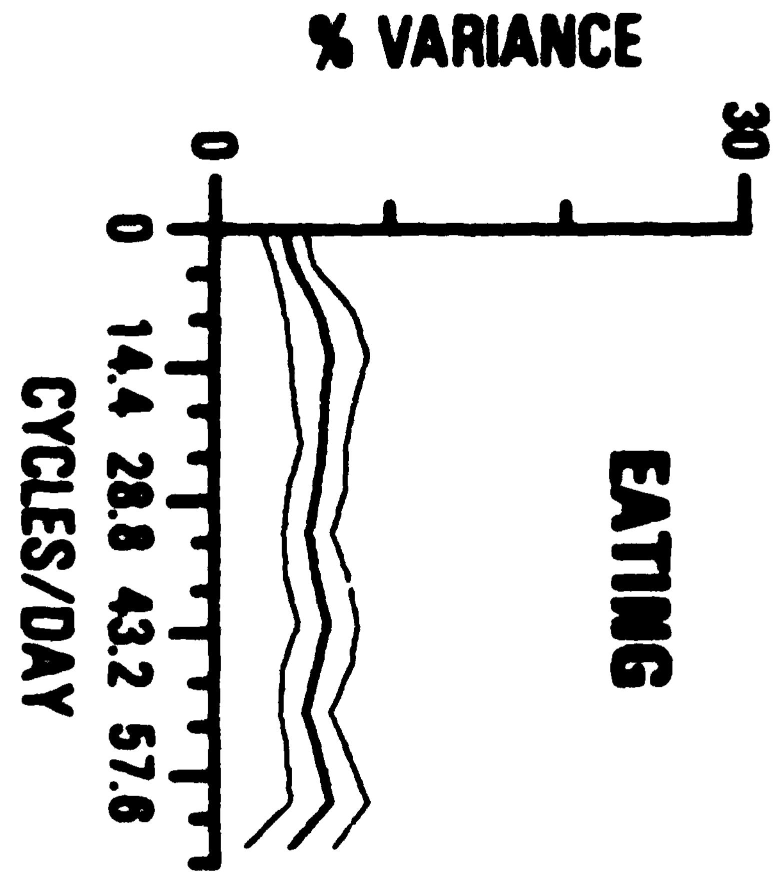


FIGURE 3:

The mean spectrum for quantity of eating.



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